



Competency 1.7 Radiation protection personnel shall demonstrate a working level knowledge of As-Low-As-Reasonably-Achievable (ALARA) principles, and their application to radiological work activities.

1. SUPPORTING KNOWLEDGE AND/OR SKILLS

- a. Describe the various components of an effective ALARA program including operations, engineering, and management controls.
- b. Describe how optimization techniques, including cost-benefit analysis, are used in the ALARA process.
- c. Discuss the essential elements of the job planning process and the post job ALARA review for work performed in a radiation or radioactive contamination area.
- d. Describe the various radiological performance indicators that are applicable to the ALARA process.
- e. Calculate person-rem estimates and use the results in ALARA cost-benefit analysis.
- f. Discuss methods to minimize total effective dose equivalent (TEDE) by evaluating the trade-offs in considering the internal and external dose components.
- g. Using knowledge of ALARA principles, discuss how to perform an evaluation of a radiation job plan and the associated worker job performance.



2. SUMMARY

Introduction to ALARA

ALARA means As Low As Reasonably Achievable, which is the approach in radiation protection to manage and control exposures (both individual and collective) to the workforce and to the general public to as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. ALARA is not a dose limit, but a process which has the objective of attaining doses as far below the applicable limits as is reasonably achievable.

Fundamental ALARA techniques include minimizing time in radiological areas, maximizing distance from radiation sources, providing adequate shielding from all radiation, providing for decontamination of personnel and equipment, and controlling ingestion and inhalation of radionuclides for all workers. Personnel responsible for ALARA should review work packages and facility design, provide awareness training for personnel, and set personnel exposure goals.

Two basic conditions are considered necessary in any program for keeping occupational exposures as far below the specified limits as is reasonably achievable. The management of the facility should be committed to maintaining exposures as low as reasonably achievable, and the personnel responsible for radiation protection should be continually vigilant for means to reduce exposures.

The control of occupational exposures is required to be implemented through facility design and engineering controls; together with procedural controls, such as work area monitoring and posting; control of work-area access; and individual monitoring and dose assessment. Collectively, these controls provide assurance that exposures are maintained ALARA.

Planning of radiological work is essential. The purpose of planning is to ensure all factors that may influence the adequate and efficient performance of a task, are recognized and that appropriate skills, training, and resources are available. The radiation work permit (RWP) is a radiation control procedure and essentially documents the planning process. The permit lists the radiation controls, requirements, and restrictions for work in a radiological area. Other important elements in the planning process are training personnel, scheduling work, briefing and debriefing workers, and documenting and analyzing historical data and work experiences. Upon completion of a task, a debriefing of those performing the work may be valuable in identifying problems encountered, techniques for improving the future performance of similar tasks, and techniques for further reducing exposures.



ALARA Program Components

The 10 CFR 835 implementation guide (IG), *Occupational ALARA Program* lists the essential elements that shall be incorporated into an acceptable occupational ALARA program:

1. Management commitment
2. Assignment of responsibility
3. Administrative control levels
4. Radiological performance goals
5. ALARA training
6. Plans and procedures
7. Internal audits/assessments
8. Optimization methodology
9. Radiological design review
10. Radiological work/experiment planning
11. Records

For the basis of this discussion, the basic components of an ALARA program to reduce dose include:

- Designing operation controls to reduce dose
- Designing engineering controls to reduce dose
- Requiring management to help design, commit to, and manage an ALARA program
- Minimizing time in radiologically controlled areas
- Maximizing the distance from a source of radiation
- Using shielding whenever possible

Operation Controls

One part of an ALARA program is to make sure the basic controls are operating at their best. To achieve this, inspection tours to check on access, mirrors, and visibility should be performed. If service inspections check the use of remote control equipment, TV, snap on insulation, platforms, etc. Other items to check include:

- Remote readout instrumentation,
- Remote valve/equipment operators
- Sampling stations, piping, valving, hoods, sinks



Administrative Controls

During operations, engineered controls are probably the most effective means of controlling exposure, if included in the design and construction of a facility. However, administrative controls, such as operational procedures, are designed to provide guidance, direction, and limitations for operational activities. Each step in a procedure should be thought through, and its impact on exposure evaluated. For example, shielding, remote operation, distance, specialized tools, protective equipment manpower requirements, exposure rates, exposure times, and alternative procedures should all be carefully considered.

DOE sites must establish a challenging level of administrative control which is more restrictive than the DOE *Radiological Control Manual* administrative control level of 2 rem/yr. As stated in the for 10 CFR 835 IG, *Occupational ALARA Program*:

"These administrative controls should be established at challenging levels, well below the controlling limit, taking into consideration the exposure history of the facility and the aggressiveness of the facility's exposure controls (*Radiological Control Manual*, Section 211). Administrative exposure controls may require increasing degrees of review, intervention and management approval before they are exceeded, depending on how close the expected dose is to the DOE occupational exposure limit. Proper implementation of the administrative control levels should prevent personnel from exceeding the DOE limits, and also aid in attaining and maintaining occupational exposures ALARA."

Workplace Monitoring

Workplace monitoring provides a control mechanism to detect and quantify external radiation levels, enables measures to be taken to prevent unanticipated and unplanned exposures, and contributes to maintaining actual exposures ALARA.

10 CFR 835, *Occupational Radiation Protection*, requires:

- Implementation of ALARA techniques to ensure that occupational exposures are maintained at ALARA levels.
- Measurements of radioactivity concentrations in workplace air be performed.
- Periodic air sampling must be performed in areas where employees are likely to exceed two percent, or more, of the annual limitation on intake (ALI) values.
- Continuous, real-time monitoring must be performed in areas where an individual could be exposed to airborne radioactivity concentrations exceeding the derived air concentration (DAC) values set forth in Appendix A to 10 CFR 835.



Radiation Protection Competency 1.7

- Real-time monitors must have an alarm capability and have sufficient sensitivity to alert potentially exposed individuals that their immediate action is necessary to minimize or terminate an inhalation exposure.
- Bioassay measurements (measurements of radioactive material within and excreted from the body) must determine the magnitude of internal doses and include directions regarding which employees should be included in bioassay programs. These measurements also confirm the effectiveness of the confinement and air monitoring systems.

Dosimeters should be appropriate for the kinds, energies, and intensities of radiation fields. The location where the dosimeter is worn on the body should be consistent and documented. The lens of the eye and the skin frequently require special consideration. Radiation surveys in the field provide a basis for making ALARA decisions in the field.

Engineering Controls

There are several engineering factors to consider when designing a facility. They include:

- The discharge of radioactive liquid to the environment
- Control of contamination
- Efficiency of maintenance
- Ease of decontamination and operations
- Selecting components to minimize the buildup of radioactivity
- Providing support facilities for donning and removing protective clothing and for personnel monitoring
- Shielding requirements
- Ergonomics consideration
- Access control designed for hazard level
- Surfaces that can be decontaminated or removed
- Equipment that can be decontaminated

The primary means for maintaining exposure ALARA should be through physical controls such as confinement, ventilation, remote handling, and shielding. Some of the factors that should be taken into consideration when designing new facilities or modifying existing ones are:

- Traffic patterns
- Radiation zoning
- Change room location and size
- Adequacy of personnel decontamination facilities



Radiation Protection Competency 1.7

- Location of fixed survey equipment

In addition, locations for the temporary storage of radioactive wastes must be designed into both the building plan and the plan for each laboratory room or radiation area.

Management Controls

Management should design and implement an ALARA program; provide resources such as tools, equipment, and adequate personnel; create and support an ALARA review committee; approve ALARA goals; and design and implement worker training.

Management commitment to minimizing radiation exposures is effected through the following aspects:

- Facility personnel should be made aware of management's commitment to keep occupational exposures ALARA.
- Management should: periodically perform a formal audit to determine how exposures might be lowered.
- Ensure that there is a well-supervised radiation protection capability with well-defined responsibilities.
- Ensure that facility workers receive sufficient training in radiation protection
- The Radiological Control Manager should be given sufficient authority to enforce safe facility operation.
- Modifications to operating and maintenance procedures and to equipment and facilities should be made where they will substantially reduce exposures at a reasonable cost.

An ALARA committee should be established at each facility. The membership should include managers and workers from the line, the technical support organization and the radiological control organization. It is more effective if a line manager, such as the director of operations, research, or maintenance serves as the chair. This committee may be part of a general safety or radiation safety committee whose functions include ALARA activities, and may possibly be combined with the radiological awareness committee (see Article 132 of the *Radiological Control Manual*) for smaller facilities.

The ALARA committee should make recommendations to management to improve progress toward minimizing radiation exposure and radiological releases. The committee should evaluate items such as construction and design of facilities and systems, planned major modifications or work activities,



Radiation Protection Competency 1.7

as well as experimental test plans for exposure, waste and release minimization. The ALARA committee should also receive, as a minimum, the results of all reviews and audits, both internal and external, and should review the overall conduct of the radiological control program.

The primary control of radiation exposures remains with the individual and with the individual's immediate supervisors. In many facilities, a major part of radiation exposure is received during maintenance, handling of radioactive wastes, in-service inspection, refueling, and repairs.

Time

The control of exposure time (time spent in a radiation field) is the first major health physics principle available to an occupational worker to limit his/her exposure to an external radiation source. It is important to realize that the radiation dose received by the worker is directly proportional to the time spent in a radiation field. Therefore, to minimize the dose received, reduce the time spent in the radiation field. Work processes and special tooling can help reduce time in a radioactive work area. The control of exposure time is a significant factor in the issuance of RWPs at DOE facilities.

- Plan and discuss the task prior to entering the area. Use only the number of workers actually required to do the job.
- Have all necessary tools present before entering the area.
- Use mock-ups and practice runs that duplicate work conditions.
- Take the most direct route to the job site, if possible and practical.
- Never loiter in an area controlled for radiological purposes.
- Work efficiently and swiftly.
- Do the job right the first time.
- Perform as much work outside the area as possible or, when practical, remove parts or components to areas with lower dose rates to perform work.
- In some cases, the radiological control personnel may limit the amount of time a worker may stay in an area due to various reasons. This is known as "stay time". If you have been assigned a stay time, do not exceed this time.

Distance

A very common and extremely effective technique to reduce personnel exposure is to increase the distance between the worker and the radiation source. In many instances, this approach is more important than controlling exposure time and can be easily demonstrated for "point" (small) sources of radiation. While the exposure-time relationship follows a direct dependence, (i.e. reducing the time spent in a radiation field by one-half reduces the exposure to the worker by one-half) distance dependence often follows the "inverse-square" (second power) law. Thus doubling the distance from a point source reduces the exposure to the worker by a factor of four! It should be noted that



Radiation Protection Competency 1.7

situations do exist where the inverse square law does not apply. In these cases, the relationship between the dose received and the distance from the source does not always follow a simple rule.

Methods for maximizing distance from sources of radiation

- The worker should stay as far away from the source of radiation as possible.
- For point sources, such as valves and hot spots, the dose rate follows a principle called the inverse square law:

$$Dose\ Rate_A = Dose\ Rate_B \left(\frac{Distance_B^2}{Distance_A^2} \right)$$

This law states that if you double the distance, the dose rate falls to 1/4 the original dose rate. If you triple the distance, the dose rate falls to 1/9 the original dose rate.

- Be familiar with radiological conditions in the area.
- During work delays, move to lower dose rate areas.
- Use remote handling devices when possible.

Shielding

Shielding the source of radiation becomes important when minimizing time and maximizing distance are not sufficient to reduce personnel exposures to acceptable levels. Determining the required shielding is influenced strongly by the type (alpha, beta, gamma, x-ray, neutron) and the energy of the radiation. Shielding is one of the basic tenets of ALARA. 10 CFR 835, Subpart K states that the shielding design objective for facilities should be 0.5 mrem/hr for areas of continuous occupancy (2,000 hrs/yr) or as far below this as possible. Material selection for shielding should include operations, maintenance, decontamination, and decommissioning.

Shielding reduces the amount of radiation dose to the worker. Different materials shield a worker from the different types of radiation.

- Take advantage of permanent shielding including nonradiological equipment/structures.
- Use shielded containments when available.
- Wear safety glasses/goggles to protect your eyes from beta radiation, when applicable.

Temporary shielding (e.g., lead or concrete blocks) can only be installed when proper procedures are



Radiation Protection Competency 1.7

used. Temporary shielding will be marked or labeled with wording such as, "Temporary Shielding - Do Not Remove Without Permission from Radiological Control." Once temporary shielding is installed, it cannot be removed without proper authorization.

It should be remembered that the placement of shielding may actually increase the total dose (e.g., person-hours involved in installing and removing shielding).

Other ALARA Program Components

Area Arrangement

- Maintenance Needs
- Radiological Control Needs

Optimization of ALARA

The optimization process in ALARA refers to the process of achieving balance between radiation protection or reduction of risk, cost, and benefit. Radiation doses are ALARA only when these factors are in balance. If an imbalance exists, either the risk is too high, or the cost is too high for the identified benefit. The optimization process should be used whenever decisions regarding the implementation of a radiation protection practice will be costly, complex, and/or involve significant dose savings, (for example, facility design and engineering controls). The major method of optimization is cost-benefit analysis, which is described in detail in ICRP 37, *Cost-Benefit Analysis in the Optimization of Radiation Protection*.

Cost-Benefit Analysis

The suggested approach to performing a cost-benefit analysis includes these steps:

- Identify all possible options, including the "do nothing" option.
- Determine the individual and collective dose equivalents for each option.
- Identify all costs and determine the net costs for each option.
- Determine the cost equivalent of the doses resulting from each option.
- Sum the costs to determine the total net cost for each option.

The option with the lowest total net cost is the optimal option.

Pre and Post ALARA Reviews



Radiation Protection Competency 1.7

Technical requirements for the conduct of work, including construction, modifications, operations, maintenance, and decommissioning, should incorporate radiological criteria to ensure safety and maintain radiation exposures ALARA. The primary methods used to maintain exposures ALARA are facility and equipment design features, augmented by administrative and procedural requirements. To accomplish this, the design and planning processes should incorporate radiological considerations in the early planning stages.

Essential Elements of Preliminary Job Planning

Preliminary Planning and Scheduling

- Plan in advance
- Delete unnecessary work
- Determine expected radiation levels
- Estimate collective dose
- Sequence jobs
- Schedule work
- Select a trained and experienced workforce
- Identify and coordinate resource requirements

Prepare Technical Work Documents

- Include special radiological control requirements in technical work documents
- Perform ALARA prejob review
- Plan access to, and exit from, the work area
- Provide for service lines (air, welding, ventilation)
- Provide communication (sometimes includes closed-circuit television)
- Remove or shield sources of radiation
- Plan for installation of temporary shielding
- Decontaminate
- Work in lowest radiation levels
- Perform as much work as practicable outside radiation areas
- State requirements for standard tools
- Consider special tools, including robots



Radiation Protection Competency 1.7

- State staging requirements for materials, parts, and tools
- Incorporate radiological control hold points
- Minimize discomfort of workers
- Revise estimates of person-rem
- Prepare radiological work permits (RWPs)

The RWP should be issued to control work activities in radiological areas, and shall be approved by the supervisor(s) in the radiation protection organization and in the organization responsible for the work before it is begun (*Radiological Control Manual*, Section 323.4). For ALARA purposes, a preliminary estimate of time and radiation dose for the activity and any special ALARA control should be provided, as appropriate (10 CFR 835 IG, *Occupational ALARA Program*). Specific criteria for the use of RWPs is outlined in the *Radiological Control Manual*, Section 322.

Prepare Temporary Shielding

- Design shielding to include stress considerations
- Control installation and removal by written procedure
- Inspect after installation
- Conduct periodic radiation surveys
- Prevent damage caused by heavy lead temporary shielding
- Balance radiation exposure received in installation against exposure saved by installation
- Shield travel routes
- Shield components with abnormally high radiation levels early in the maintenance period
- Shield position occupied by worker
- Perform directional surveys to improve design of shielding by locating source of radiation
- Use mock-ups to plan temporary shielding design and installation
- Consider use of water-filled shielding



Rehearse and Brief

- Rehearse
- Use mock-ups duplicating working conditions
- Use photographs and videotapes
- Supervisors conduct briefings of workers

Perform Prejob ALARA Reviews

A prejob ALARA review should be conducted for non routine or complex radiological work activities. Specific requirements for the conduct of a prejob ALARA review should be included in the site-specific contractor radiological control program. A prejob ALARA review is indicated when any of the following trigger levels may be met during the work evolution:

- Estimated individual or collective dose greater than preestablished values
- Predicted airborne radioactivity concentrations in excess of preestablished values
- Work area where removable contamination is greater than 100 times contamination area posting limits
- Entry into areas where dose rates exceed one rem/hour
- Potential radioactive releases to the environment

Radiological requirements identified as part of the prejob ALARA review should be documented in the job plans, procedures or work packages. The prejob ALARA review should consider the following points, at a minimum:

- Inclusion of radiological control hold points in the technical work documents
- Elimination, or reduction, of radioactivity through line flushing and decontamination
- Use of work processes and special tooling to reduce time in the work area
- Use of engineered controls to minimize the spread of contamination and generation of airborne radioactivity
- Specification of special radiological training or monitoring requirements
- Use of mock-ups for high-exposure or complex tasks
- Engineering, design and use of temporary shielding to reduce radiation levels
- Walkdown or dry-run of the activity using applicable procedures
- Staging and preparation of necessary materials and special tools
- Maximization of prefabrication and shop work
- Review of abnormal and emergency procedures and plans



Radiation Protection Competency 1.7

- Identification of points where signatures and second party or independent verifications are required
- Establishment of success or completion criteria, with contingency plans to anticipate difficulties
- Development of a prejob estimate of collective dose to be incurred for the job
- Provisions for waste minimization and disposal

Perform Prejob briefings

Any work evolution requiring a prejob ALARA review should also include a prejob briefing to be held prior to the conduct of work. Specific requirements for the conduct of a prejob briefing should be included in the site-specific contractor radiological control program. Prejob briefings should be conducted by the cognizant work supervisor and should include, at a minimum, the following details:

- Scope of work to be performed
- Radiological conditions of the workplace
- Procedural and RWP requirements
- Special radiological control requirements
- Radiologically limiting conditions, such as contamination or radiation levels that may void the RWP
- Radiological control hold points
- Communications and coordination with other facility work groups
- Provisions for housekeeping and final cleanup
- Emergency response provisions

Essential Elements of Post Job Reviews

Post-job ALARA reviews should be held, following conduct of radiological work, according to the site-specific contractor radiological control program. Typical criteria for work evolutions which will require a postjob ALARA review are:

- Any job requiring a prejob ALARA review
- The actual collective dose exceeding the estimated collective dose by at least 25%
- The work evolution was nonroutine

A postjob briefing gives the radiological control technician and the workers the opportunity to critique the work performance. During the critique, information is gathered as soon as possible after the job is completed while it is still fresh in everyone's mind. The information gathered at the postjob briefing may include discussions of what went wrong, what could have been done differently or



Radiation Protection Competency 1.7

reduce exposures, and what went right. The postjob briefings rely heavily on the input of each worker for information on how to best reduce exposure the next time that job is performed. Typical questions asked at a postjob briefing are:

1. Were there any problems performing the job in accordance with the procedure?
2. Did you have the tools and equipment needed to perform the work? Would special tools ease the job?
3. Were there any unexpected conditions noted during the work? Could these conditions have been anticipated?
4. Were there any unexpected delays in the performance of the job? What was the cause of the delay?
5. Was temporary shielding used? Could the use of temporary shielding reduce exposures received for this job?

Do not limit yourself to just these questions. The brief should be a dynamic exchange of information between all parties.

Postjob ALARA Reviews

Information gathered from the postjob briefing will then be evaluated by ALARA engineers. A postjob ALARA review is a formal document that evaluates what went right, as well as, what went wrong, determining root causes and instituting corrective measures. This documentation will then be filed for future use, enabling ALARA engineering to write a prejob ALARA review incorporating corrective measures from lessons learned. The postjob ALARA review is a formal preservation of lessons learned information and is important to ascend the learning curve and help maintain ALARA.

ALARA Performance Indicators

DOE-STD-1048-92, *DOE Performance Indicators Guidance Document*, gives specific guidance on the use of performance indicators in the ALARA program assessment process.

Goals for individual and collective doses should be established and actual doses received should be tracked to improve the performance of nonroutine and high-exposure radiological tasks. Line management should document the goals, their status, and the facility's performance. At least annually, a formal summary of performance related to efforts in dose reduction and contamination minimization, and in achievement of the site's or facility's radiological goals should be given to senior management in an ALARA report. This information can then be used to feed back into the prejob and postjob briefings.

The radiological performance indicators listed below are suggested by the *Radiological Control*



Radiation Protection Competency 1.7

Manual as tools to assist facility management in focusing priorities to establish excellence in radiological control. Table 1, following, provides indicators that can be used to conduct a more detailed analysis of radiological performance.

- Collective Dose (person-rem): This goal should be based upon planned activities and historical performance. For those sites that have neutron radiation, a goal for collective neutron dose should also be established.
- Skin and Personal Clothing Contamination Occurrences (number): Personnel contaminations may indicate a breakdown of controls intended to prevent the spread of contamination.
- Intakes of Radioactive Material (number): Personnel intakes of radioactive material should be minimized and management should focus attention on any failure of the controls that results in intakes.
- Contaminated Area Within Buildings (square feet): Operating with a smaller contaminated area results in less radioactive waste, fewer personnel contaminations, and improved productivity. The reduction of existing contaminated areas needs to be balanced by the recognition that this generates radioactive waste. Goals for both should be correlated.
- Radioactive Waste (cubic feet): Minimizing the generation of radioactive waste reduces the environmental impact of DOE operations, helps reduce personnel exposure, and reduces costs associated with handling, packaging, and disposal.
- Liquid and Airborne Radioactivity Released (curies): Minimizing effluents reduces the environmental impact of DOE operations and reduces the costs associated with remediation.

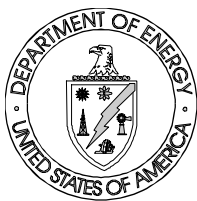


Table 1 Suggested Radiological Performance Indicators

<p>Exposure control</p> <ul style="list-style-type: none"> A. Collective dose in person-rem B. Average worker dose in rem C. Maximum dose to a worker in rem D. Number of unplanned exposures resulting in doses greater than the administrative control level E. Number of dose assessments for lost or damaged dosimeters F. Maximum neutron dose to a worker in rem
<p>Personnel Contamination</p> <ul style="list-style-type: none"> A. Number of skin and personal clothing contaminations B. Number of contaminated wounds C. Number of facial contaminations
<p>Control of Internal Exposure</p> <ul style="list-style-type: none"> A. Number of new confirmed depositions B. Number of airborne events C. Number of alarms on airborne monitors (actual and false) D. Number of airborne radioactivity areas E. Area of airborne radioactivity areas in square feet
<p>Control of Contaminated Areas in Operational Areas</p> <ul style="list-style-type: none"> A. Number of contamination and high contamination areas B. Area of contamination areas in square feet C. Area of high-contamination areas in square feet D. Number of spills
<p>Minimization of Radioactive Waste</p> <ul style="list-style-type: none"> A. Volume and activity of radioactive waste in cubic feet and curies, respectively B. Number of cubic feet not subject to volume reduction by incineration, compaction, or other means
<p>Control of Radioactive Discharges</p> <ul style="list-style-type: none"> A. Activity of liquid-radioactivity discharges in curies B. Activity of airborne-radioactivity discharges in curies



Cost-Benefit Analysis

The use of cost-benefit analysis in the ALARA process involves assigning a dollar value to a person-rem and comparing that against the cost of implementing a particular exposure-reduction technique. Such techniques include system and facility design modifications, addition of engineering controls, and modifications to administrative controls. If the cost of the change is less than the dollar value of person-rem saved by the change, the change is cost effective and should be implemented. ICRP 37, *Cost-Benefit Analysis in the Optimization of Radiation Protection*, gives specific guidance on the calculational methods used to arrive at a dollar value for a person-rem. PNL-6577 *Department of Energy Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that are As Low As Reasonably Achievable (ALARA)*, uses \$1,000 per person/rem in all examples and calculations.

Person-Rem Calculations

Problem

A ventilation system would lower the average annual TEDE at a radioactive gas-handling facility by 1.5 rem. Fifteen workers work regularly at the facility. What annualized cost, over the life of the ventilation system, would justify the addition of the system?

Solution

Calculate the collective annual person-rem saved by multiplying the average annual dose saved by the number of workers:

$$1.5 \text{ rem} \times 15 \text{ persons} = 22.5 \text{ person-rem}$$

Since DOE policy dictates a value of \$1,000 per person-rem saved, calculate the justifiable annualized cost of the ventilation system by multiplying the person-rem dollar value by the collective person-rem saved:

$$\$1,000/\text{person-rem} \times 22.5 \text{ person-rem} = \$22,500$$

Therefore, if the ventilation system can be added for an annualized cost of less than \$22,500, the system should be implemented. Remember, annualized cost means the total cost divided by the remaining operating life of the facility.



ALARA Cost-benefit analysis

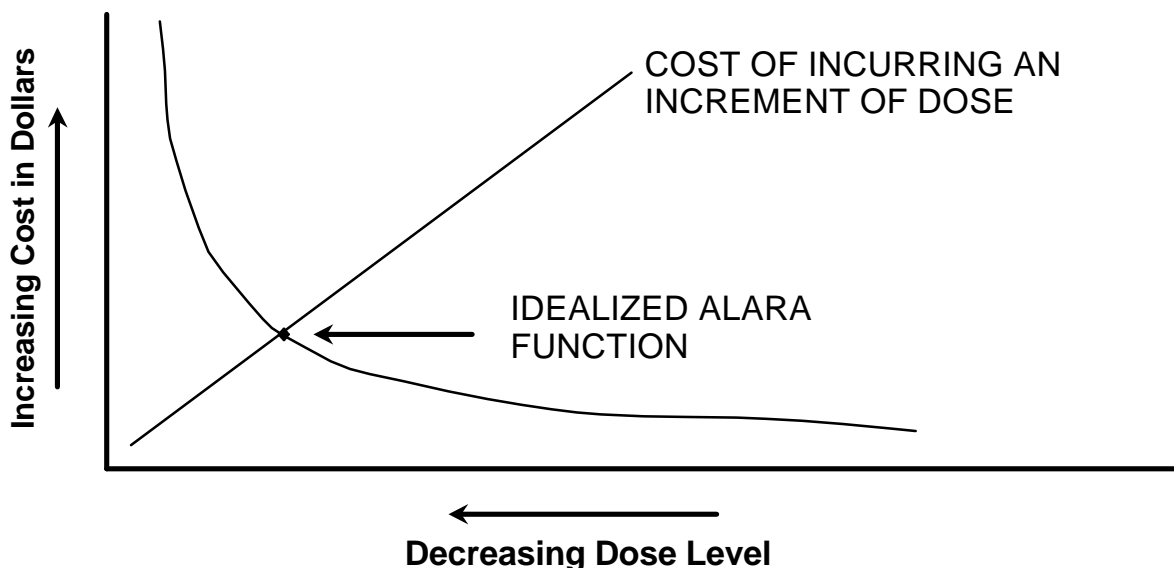
The International Commission on Radiological Protection (ICRP) has attempted to further analyze the "...economic and social factors" in ICRP 55. The DOE and the Nuclear Regulatory Commission (NRC) have also addressed this issue in various publications and regulatory guides. The objective is to optimize dose reduction activities, (i.e., to determine at what point additional expenditures will not result in cost effective dose savings). To put it another way, at what point would the money spent on dose reduction be better spent reducing other hazards which may pose greater risks? How much, in dollars, is a rem worth?

Using the BEIR V Report, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, 1990, estimates on risk, values of \$2,000 to \$10,000 per rem have been suggested.

The values to be used depend on other factors, including:

- Perception or acceptance of the risk
- Who benefits and who is at risk
- Individual dose distributions (e.g., a percent of some limit)
- Time distribution of doses (e.g., "tails" of rad waste burial dose curves)
- The probability that the dose will actually be received (such as in design considerations),
- Additional factors including population age distributions and occupational vs. general population doses

Cost-benefit can be shown graphically:



Minimizing TEDE Dose



Radiation Protection Competency 1.7

In past years, the common practice at nuclear facilities has been to always wear a respirator if there is airborne radiation present at the work site. However, when analyzed in terms of ALARA, this practice may not be the best solution for a particular job. In order to minimize the total effective dose equivalent (TEDE), radiation protection personnel must analyze the internal (airborne) dose and compare it to the external dose.

The use of respirators must be analyzed carefully at the start of each job, because there are a number of negative effects to the wearer. The use of respirators causes impairment of communication, added stress, reduced workmanship, and increased time in the radioactive area (when wearing a respirator, assume a 20% increase in work time). If the external dose received due to the increased work time is higher than the internal dose saved, then it would be ALARA not to wear a respirator in order to limit the time spent in the radiation field.

The equation shown can be used to below determine the incremental external dose incurred due to the increase in work time (assuming 20%) by using a respirator, and comparing it to the internal dose rate of 2.5 mrem per DAC hour¹.

Example

Assume the external dose rate is 100 mrem/hr and respirators increase work time by 20%. At what airborne concentration, in DAC, are respirators ALARA?

$$\frac{100 \text{ mrem/hr} \times 0.20}{2.5 \text{ mrem/DAC} \cdot \text{hr}} = 8 \text{ DAC}$$

¹ **Derived air concentration (DAC):** For the radionuclides listed in Appendix A of 10 CFR 835, the airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2,000 hours (assuming a breathing volume of 2,400 m³). For radionuclides listed in Appendix C of 10 CFR 835, the air immersion DACs were calculated for a continuous, nonshielded exposure via immersion in a semi-infinite atmospheric cloud. The values are based upon the DAC found in Table 1 of the U. S. Environmental Protection Agency's Federal Guidance Report No. 11 *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*, September 1988.



3. SELF-STUDY SCENARIOS/ACTIVITIES AND SOLUTIONS

Exercise 1

Following a major repair of some contaminated equipment, the work area needs to be picked up. The work area is about 30 feet by 30 feet square. The initial plan calls for a worker to go into the contamination area to pick up debris. The debris consists mainly of absorbent paper, plastic, tools, and broken parts. The debris is to be sorted and disposed of in two radioactive waste containers located in the contaminated area. The ambient dose equivalent rate in the area is about 10 mrem/hr, with two marked areas of contamination where the dose equivalent rates are on the order of 6 mrem/hr (at 1 meter). The dose equivalent rates are attributable to gamma rays, and no airborne activity is present. In the corner of the work area is a small area that is roped off and properly labeled as a high-radiation area. It is anticipated that it will take a worker in full protective clothing 9 minutes to do the job.

Briefly list important ALARA elements in the performance of this job that would begin to provide the basis for the RWP, and subsequent briefing of the worker. Estimate the dose equivalent to this worker for this job.

Your Solution:



The worker was briefed on the objective of the job and the items on the RWP. The worker entered the area, and began to pick up debris. After a while he noticed that the radioactive waste containers were located right next to one of the spots with the highest contamination. He immediately dismissed this thought and decided to keep doing the task at hand. Upon being notified that the 30 minutes had elapsed, the worker removed the protective clothing, was fished for contamination, and left the area. The worker's dosimeter read 10 mrem. A debriefing was held after the job was completed.

Your Solution:

[illegible]



Radiation Protection Competency 1.7

Exercise 3

Some vacuuming of radioactive dust needs to be performed around the vicinity of an accelerator. The magnet coils of the accelerator were recently repaired and some grinding of welds were necessary, resulting in radioactive dust to be cleaned up. The area where the vacuuming is needed is correctly posted as an airborne-radioactivity area, a high-radiation area, and a contamination area. Several options exist regarding the radiological aspects of performing the vacuuming work. The health physics supervisor is examining several options before writing up the RWP.

Specific information about the work area is listed below:

- Primary contaminant is manganese-54 (Mn-54) oxide.
- Ambient dose equivalent rate is 10 rem/hr.
- Job will take approximately 1.5 hours to perform.
- Measured airborne concentration is five times the DAC.
- A movable shield with arm ports could be used between the worker and the bulk of the dust to be picked up. This shield attenuates the dose equivalent rate to 1 rem/hr, but will increase the estimated job duration time to two hours.
- Respiratory protection with a protection factor (PF) of 50 is available, but will increase the estimated job duration time to three hours.

The health physics supervisor is examining the following options. All options assume that protective clothing will be worn during the job.

1. Use one worker, no shield, and no respiratory protection.
2. Use one worker, the shield, and no respiratory protection.
3. Use one worker, the shield, and respiratory protection.

Estimate the total dose equivalent to the worker under for each option, and identify the option with lowest total dose equivalent.

Your Solution:

Exercise 4



Radiation Protection Competency 1.7

What are some other options that the health physics supervisor might consider?

Your Solution:

Exercise 5

Identify a sensitive issue that the health physics supervisor can expect to arise when instructing the workers about the performance of this particular task.

Your Solution:



Exercise Solutions

Exercise 1, Solution

(Any reasonable paraphrase of the following is acceptable.)

The RWP will list the radiation controls, requirements, and restrictions for the work. The following are some elements relevant to this job:

- Since the area is a contamination area, protective clothing is necessary and must be worn. The clothing should probably consist of coveralls, gloves, shoe covers, and hood.
- The worker should wear at least a whole body dosimeter and pocket dosimeter.
- The worker should minimize the time near the most contaminated areas.
- The worker should be instructed not to go into the high-radiation area to pick up debris.
- The worker should be instructed to pick up as much as possible in the 30-minute time frame, and then exit the area.
- A supervisor should be outside the area to monitor the worker's time spent in the area, answer questions from the worker, and supervise the work.

A quick estimate of the dose equivalent to the worker would be:

$$(10 \text{ mrem/hr}) (0.5 \text{ hr}) = \mathbf{5 \text{ mrem}}$$

Exercise 2, Solution

(Any reasonable paraphrase of the following is acceptable.)

The debriefing should include the following items:

- Was the objective of the RWP met? Was the debris picked up and placed in the radioactive waste cans? Was the task completed, or was there more debris remaining that could not be picked up in the allowed time frame?
- Did the worker stay out of the high-radiation area in the corner?
- Did the worker encounter any unanticipated problems that were not addressed in the RWP?
- Was the protective clothing appropriate for the situation (i.e., did it fail; would another type of clothing, or glove, etc., have worked better for the job to be performed)? Was it safe for the employee considering factors such as heat, humidity, lighting, water, etc.? Did it prevent contamination of the employee?
- Did the worker avoid the areas with the highest contamination?
- Were the pocket ionization chamber results within the limit set for the job? If not, what factor(s) contributed to additional exposure?
- What can be improved when other similar jobs have to be performed?

It appears that the job was performed according to plan with these exceptions: The worker had to



Radiation Protection Competency 1.7

spend more time than necessary near the areas of highest contamination since the radioactive waste containers were located there, and the worker's estimated dose equivalent for the job was greater than anticipated, perhaps for the same reason. As far as the worker's performance, he did notice the proximity of the waste containers to the contaminated pots, but did not question this. He could have moved the containers to a different location in the area, or asked the supervisor who, was outside the area, about what to do in this situation. This may have contributed to the higher-than-estimated dose equivalent that the worker received. For future jobs, the workers could be instructed to move the containers to an area away from areas of highest contamination.

Exercise 3, Solution

Option 1: No shield, no respiratory protection

External exposure:	(10 rem/hr) (1.5 hr)	=	15 rem
Internal exposure:	(5 DAC) (1.5 hr)	=	7.5 DAC-hours
	(7.5/2000 DAC-hrs) (5 rem)	=	0.01875 rem or about 19 mrem
Total dose equivalent:	15 rem + 19 mrem	=	15.019 rem

Option 2: Use shield, but no respiratory protection

External exposure:	(1 rem/hr) (2 hr)	=	2 rem
Internal exposure:	(5 DAC) (2 hr)	=	10 DAC-hours
	(10/2000 DAC-hrs) (5 rem)	=	0.025 rem or 25 mrem
Total dose equivalent:	2 rem + 25 mrem	=	2.025 rem

Option 3: Use shield, use respiratory protection

External exposure:	(1 rem/hr) (3 hr)	=	3 rem
Internal exposure:	(5 DAC/50 PF) (3 hrs)	=	3 DAC-hours
	(0.3/2000) (5 rem)	=	0.75 mrem
Total dose equivalent:	3 rem + 0.75 mrem	=	3.00075 rem or 3 rem

Clearly, Option 2 results in the lowest total dose equivalent. All other factors being equal, this would be the best option.

Exercise 4, Solution

The health physics supervisor might consider using several people in short shift to perform the task. The advantage here is that the dose would be distributed among several individuals. This option would be especially attractive in meeting site-specific administrative controls.

Exercise 5, Solution



Radiation Protection Competency 1.7

A sensitive issue that will arise on the part of the workers is why respiratory protection is not needed in an airborne activity area. The health physics supervisor must be very careful to explain the primarily external hazard associated with this particular radionuclide, even though dust containing the radionuclide is present. Also, the health physics supervisor must be sure to explain that the total risk to the individual is the result of BOTH internal and external exposure. This will be easier for the workers to accept if they have been properly trained to begin with, and if they are not hearing this concept for the very first time.



4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

Readings

- 10 CFR 835, *Occupational Radiation Protection*.
- DOE N 441.1, *Radiological Protection for DOE Activities*.
- DOE/EH-0256T (Revision 1), *Radiological Control Manual*.
NOTE: See Appendix 3A, Checklist for Reducing Occupational Radiation Exposure, pp. 3-35 & 3-36.
- DOE Order 5480.4, *Environmental Protection, Safety, and Health Protection Standards*
- G-10 CFR 835, Revision 1, *Implementation Guides for Use with Title 10 Code of Federal Regulations 835*.
- International Commission on Radiological Protection. *Cost-Benefit Analysis in the Optimization of Radiation Protection (ICRP 37)*. New York: Author.
- International Commission on Radiological Protection. *Recommendations on the International Commission of Radiological Protection (ICRP 60)*. New York: Author.
- Pacific Northwest Laboratory. (1988). *Department of Energy Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that are As Low As Reasonably Achievable (ALARA)* (PNL-6577). Richland, WA: Author.
- Beir V Report, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, 1990.

Courses

- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Fundamental Radiological Control*, sponsored by the Office of Defense Programs, DOE.
- *Applied Health Physics* -- Oak Ridge Institute for Science and Education.
- *Health Physics for the Industrial Hygienist* -- Oak Ridge Institute for Science and Education.
- *Safe Use of Radionuclides* -- Oak Ridge Institute for Science and Education.
- *Radiation Protection Functional Area Qualification Standard* -- GTS Duratek.